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ON THE INTERACTION BETWEEN SIX TYPES OF COCKPIT CONTROLLERS, PILOTS, AND CONTROL SURFACES

Report No. KU-FRL-484-2

by

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49

TABLE OF CONTENTS

LIST OF SYMBOLS

(in order of appearance)

Symbol	Definition	Dimension
(P)	Pedal	-
(S)	Stick	-
(W)	Wheel	-
(B)	Brolley	-
(SA)	Side-arm	-
F	Control Force	lbs
G	Gearing Ratio	ft^{-1}
HM	Hinge Moment	ft-lbs
C_{h_δ}	Hinge Moment Derivative, $\frac{\partial C_h}{\partial \delta}$	deg^{-1}
C_h	Hinge Moment Coefficient	-
δ	Control Surface Deflation	deg
$\bar{q}$	Dynamic Pressure	lbs ft^{-2}
S_x	Control Surface Area	ft^2
$\bar{c}_x$	Control Surface Mean Geometric Chord	ft
$C_{\ell_{\delta_A}}$	Aileron Control Power Derivative, $\frac{\partial C_\ell}{\partial \delta_A}$	deg^{-1}
C_ℓ	Rolling Moment Coefficient	-
$C_{n_{\delta_R}}$	Rudder Control Power Derivative, $\frac{\partial C_n}{\partial \delta_R}$	deg^{-1}
C_n	Yawing Moment Coefficient	-
$C_{m_{\delta_E}}$	Elevator Control Power Derivative	deg^{-1}
C_m	Pitching Moment Coefficient	-

LIST OF SYMBOLS (continued)

Symbol	Definition	Dimension
W	Weight	Kgf or lbs
b_w	Wing Span	m or ft
S_w	Wing Area	m^2 or ft^2
$\bar{c}_w$	Wing Mean Geometric Chord	m or ft
A	Aspect Ratio (Wing)	-
Λ	Quarter Chord Sweep Angle (Wing)	deg
λ	Taper Ratio (Wing)	-
Γ	Dihedral Angle	deg
S_v	Vertical Tail Area	m^2 or ft^2
S_h	Horizontal Tail Area	m^2 or ft^2
ℓ_v	Vertical Tail Moment Arm	m or ft
ℓ_h	Horizontal Tail Moment Arm	m or ft
S_a	Aileron Area	m^2 or ft^2
S_e	Elevator Area	m^2 or ft^2
S_r	Rudder Area	m^2 or ft^2
S_E	Flap Area	m^2 or ft^2

Subscripts

E	Elevator
A	Aileron
R	Rudder
X	Any Surface

INTRODUCTION

This report is written as part of the documentation required under NASA Grant NAG 1-94.

In addition to this report, Reference 1 was submitted to NASA Langley.

The purpose of this report is to define and discuss the following:

1) Travel, size, location, and forces associated with six types of cockpit controllers
2) Sizing of control surfaces associated with the same six types of cockpit controllers
3) Interfacing of control surfaces with six types of cockpit controllers.

Chapters 1, 2, and 3 contain the required information.

Although the material in this report was to deal only with single-engine airplanes, much material also applies to multi-engine airplanes.

CHAPTER 1

CHARACTERISTICS OF CONTROLLER TYPES

The following characteristics of six types of cockpit controllers for piloted airplanes are presented in this chapter:

- controller travel
- controller size
- controller location
- controller forces

These characteristics are given for the following controller types:

- Pedals (P)
- Stick (S)
- Wheel (W)
- Brolley (B)
- Side-arm (SA)

1.1 EXAMPLE APPLICATIONS OF CONTROLLER TYPES

Table 1.1 provides a list of airplanes and types of cockpit controllers used. The Brolley type is missing because it has not (yet?) been applied to production type single engine airplanes.

Table 1.1 Example Cockpit Control and Control Surface Applications

Airplane Type and (Controller Type)	Primary Flight Controls		
	Longitudinal	Lateral	Directional
Cessna 152 (WWP)	Elevator	Frise Ailerons	Rudder
Cessna Cardinal (WWP)	Tab Controlled Stabilator	Frise Ailerons	Rudder
Cessna Centurion (WWP)	Elevator	Frise Ailerons	Rudder
Maule Rocket (WWP)	Elevator	Ailerons linked to →	Rudder
Piper Warrior (WWP)	Stabilator with Anti-servo Tab	Ailerons	Rudder
Piper Lance (WWP)	Stabilator	Ailerons	Rudder
Piper Tomahawk (WWP)	Elevator	Ailerons	Rudder
Robertson STOL Conversions (WWP)	Elevator	Spoilers	Rudder
Rutan Varieze (SASAP)	Canardvator	Ailerons	Rudders (2)
Piper Cub (SSP)	Elevator	Aileron	Rudder
ERCO Aircoupe (WW)*	Elevator	Aileron	Rudder

Note: For explanation of ( ) notation, see page 2.

*Aileron and Rudder geared together

1.2 GEOMETRY OF COCKPIT CONTROLLERS

1.2.1 Standard Controllers: Stick, Wheel and Pedals (Europe)

A fixed arrangement of the standard cockpit controllers in relation to the pilot seat is not practical. The reason for this is the wide variation of body dimensions found in adults. For example:

a) The measured variation in leg length is > ± 20 cm.

b) The measured variation in arm length is > ± 15 cm.

c) The measured variation in distance from seat to eye is > ± 12 cm.

It is noted that no systematic relationship has been found to exist between the quantities under a), b), and c). Figure 1.1 shows an example of typical variations in body dimensions in a typical cockpit attitude.

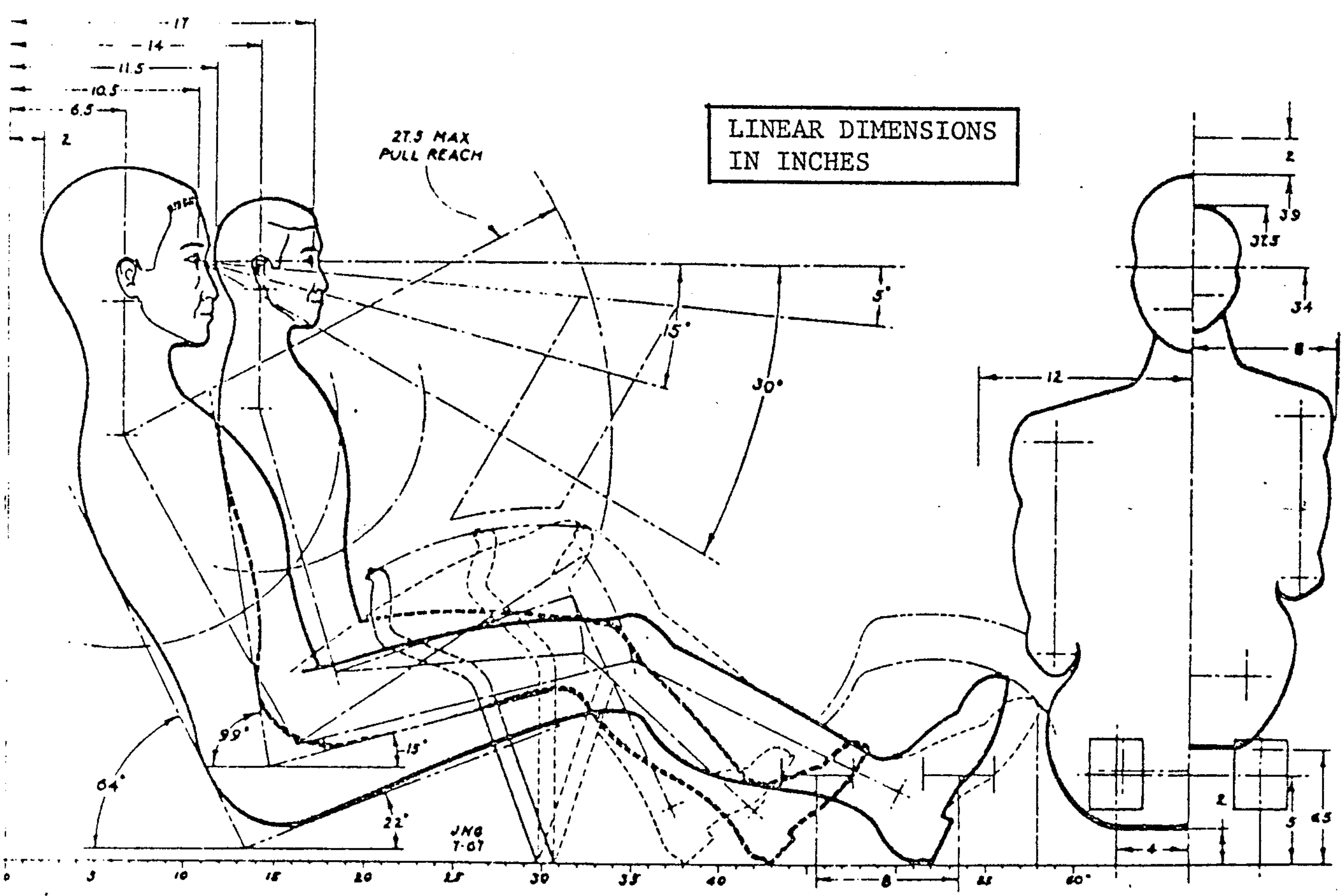


Figure 1.1 Illustration of Variation of Pilot Sizes

In many transport and fighter airplanes it is possible to adjust the center position of the rudder pedals. This is to accommodate differences in leg length. In nearly all airplanes (including single-engine general aviation airplanes) it is possible to adjust the pilot seat forward or backward. This is to accommodate differences in arm length. In many instances it is also possible to adjust the seat height, to compensate for differences in eye height.

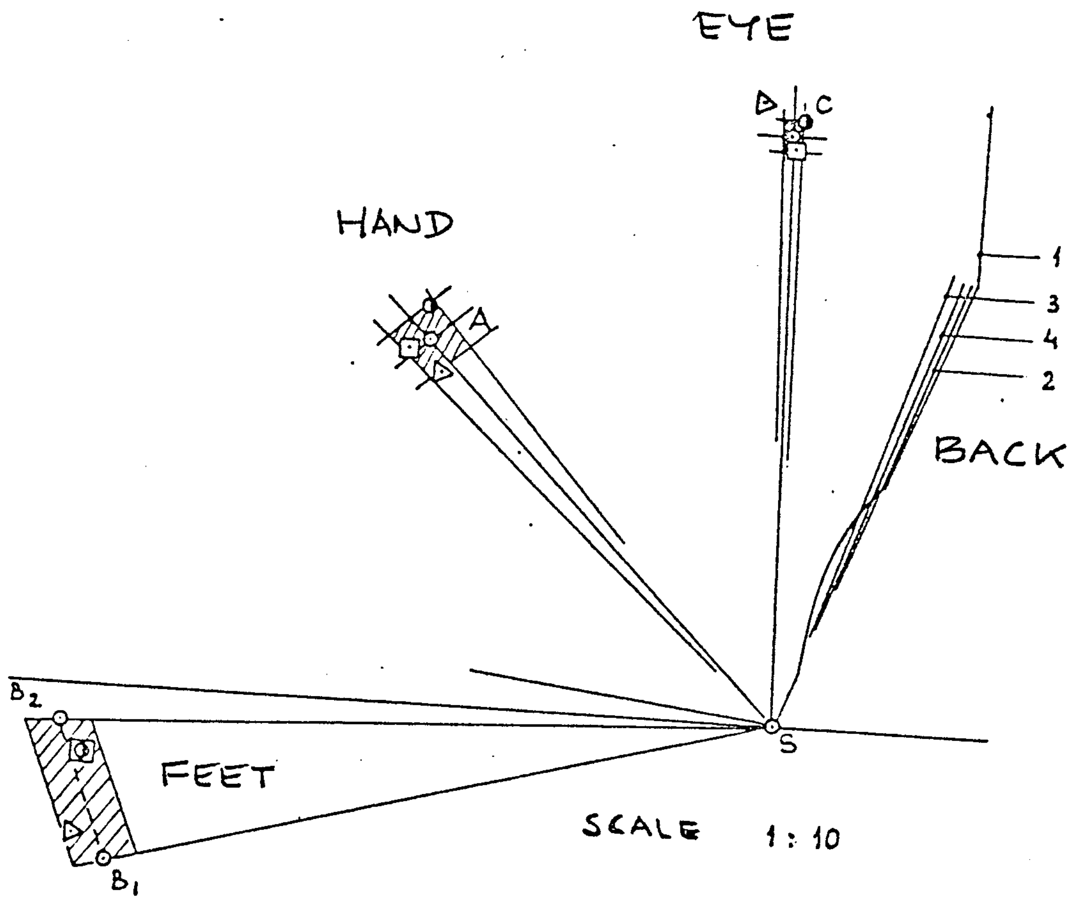
There exist large differences in seat versus controls arrangement between various airplanes. To make matters more difficult, there is not much agreement between cockpit - arrangement - dimensions from various contries. This is illustrated in Figure 1.2.

It is good design practice during the layout design of an airplane cockpit to actually make a cardboard or plastic pilot-puppet according to Figure 1.3. This puppet should be made to the same scale as the one selected for development of the airplane cockpit and fuselage interior drawings. This puppet can then be used to develop quickly interior and exterior dimensions of the cockpit area.

Table 1.2 lists typical data for the weights of body items 1-7 (Figure 1.3) and for the lengths identified in Figure 1.3. These data are averages for male crew members.

As stated before, cockpit controls must be arranged in such a manner that pilots of varying body sizes can reach and use all controls in a comfortable manner. Figure 1.4 and Table 1.3 show recommended dimensions of quantities which determine whether or not a pilot can reach and use the controls. Extremes on control travels are thus defined. These data have been obtained from systematic measurements on human subjects. Most dimensions include a tolerance band. Any dimension within these tolerance bands is acceptable in such cases.

It is a fact that in transport and bomber type airplanes, the β-values of Figure 1.4 and Table 1.3 are slightly larger than those indicated. For other types of airplanes the β-values are slightly less than those indicated in Table 1.3. It has been found that in case of a positive tolerance on $(\zeta + \phi)$, this must be combined with a negative tolerance in C and a positive tolerance in γ.



1. English Standard Proposal AM/1004/7 ▷

2. French Standard Proposal Aero 82-220 ⊡

3. U. S. WADC Measurement ◑

4. Dutch Standard Proposal 1824 ⊙

Figure 1.2 Overlap of Dimensions Defining Relative Controls to Seat Dimensions of Various Countries

Table 1.2 Dimensions and Weights of the Human Body

Weights of Body Components (~80 kg Male)		
Component	No*	Kgf
Head and Neck	1	6.8
Upper Torso	2	22.2
Lower Torso	3	12.7
Upper Legs	4	18.1
Lower Legs and Feet	5	13.5
Upper Arms	6	4.5
Lower Arms and Hands	7	3.5
Total		81.3
All weights include flight clothing and helmet		

*See Figure 2.1 for identification of numbers and symbols.

Average Weights for Crew and Passengers		
Male:	80 kgf	excludes any and all luggage
Female:	65 kgf	
Child (2-12 yrs):	35 kgf	
Child (<2 yrs):	15 kgf	
All weights include winter clothing		

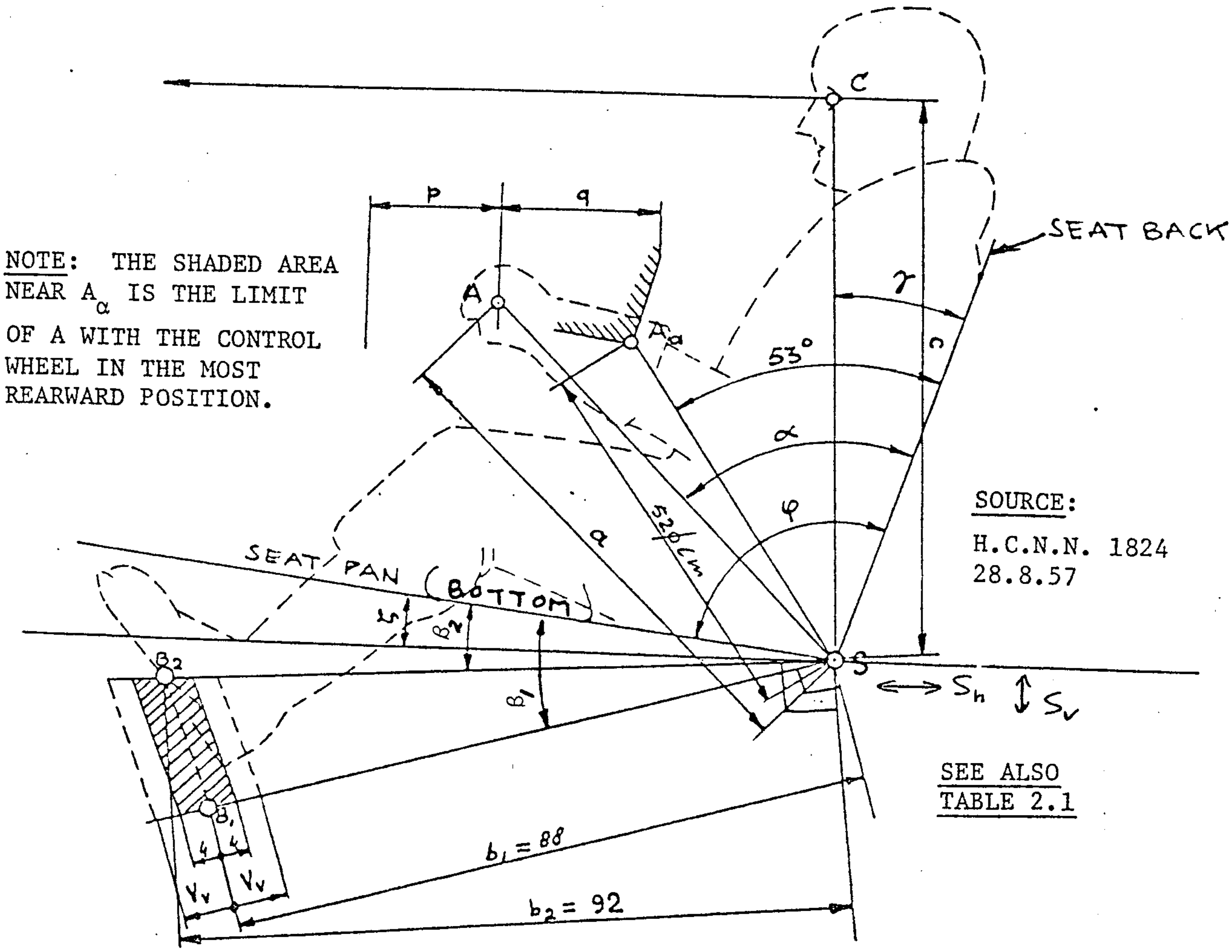
Dimensions in mm except as indicated

Sources: DIN9100, Dutch Norm V1809 and Design Requirements RAF and RN

Body Length*	a	b	c	d	e	f	g	h	i	k	l	m	n	o	p	q	r	s	t
1.60 m		870	230	300	620	350	435	850	140	760	300	300	50	200	190	260	80	25	20
1.75 m		920	255	335	685	390	475	950	150	805	330	325	60	220	200	270	90	30	30
1.90 m		990	280	370	750	430	515	1050	160	875	360	350	70	240	210	280	100	30	20

Torso	Width across Elbows	600	
	Width across Hips	400	
	Depth of Chest and Belly	300	
Hand	Width of Hand measured across Palm without Thumb	100	All Dimensions include winter clothing
	Hand thickness	45	
	Pointing finger thickness	25	
Leg	Width of thigh at 1/2 g	200	
	Thickness of thigh at 1/2 g	180	
	Knee width (bent)	150	
Foot	Width of shoe or boot	130	
	Width of shoe across root of toes	80	

NOTE: THE SHADED AREA NEAR A_α IS THE LIMIT OF A WITH THE CONTROL WHEEL IN THE MOST REARWARD POSITION.



SOURCE:

H.C.N.N. 1824
28.8.57

SEE ALSO TABLE 2.1

Figure 1.4 Recommended Dimensions for Pilot Controls Relative to the Pilot Seat

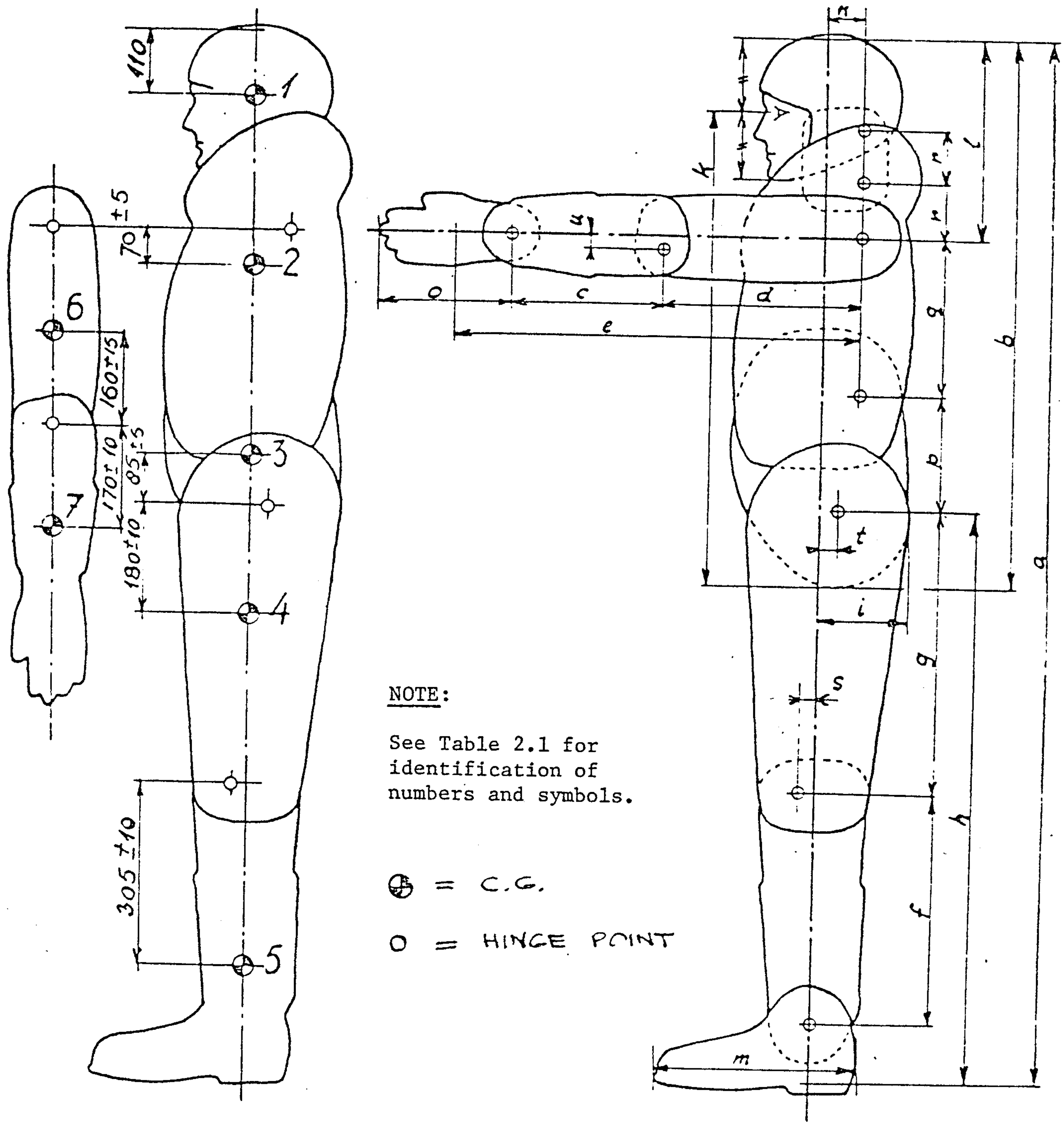


Figure 1.3 Standard Dimensions for Male Crew Members (Winter Clothing)

Table 1.3 Dimensions for Cockpit Controls and Seat Adjustment (cm. or deg.)

Note: Symbols Refer to Figures 2.2 and 2.3	Airplanes with Wheel (cm or deg)	Airplanes with Stick (cm or deg)
a	67±4	63±4
ζ	7°±2°	7°±2°
p Forward motion of A	18±2	16±2
q Rearward motion of A	22±2	20±2
r Sidewise motion of A from center	----	15±2
d Distance between handgrips of wheel	38±5	----
ε Wheel rotation (to roll) from center	85°max	----
υ Distance between rudder pedal center lines	38±12	45±5
α	64°±3°	70°±3°
β_1	22°	
β_2	10°	
c	77±2	
γ	21°±1°	
ϕ	102°±2°	
(1)V_v Adjustment range of pedals from center position B	7±2	
(1)U_v Forward and aft pedal motion from center position B	10±2	
S_h Horizontal adjustment range of S from center position	≤ 10	
S_v Vertical adjustment range of S from center position	8±1	

NOTE: Pedal adjustment and pedal motion must take place approximately along a line SB. If the heel rests on the floor it is necessary for the latter to be parallel to SB and 13 cm. below SB. Point B is assumed to be 15±1 cm. from the backside of the shoe.

1.2.2 Standard Controllers: Stick, Wheel and Pedals (USA)

In the USA the data of Military Standard (MS) 33573 are normally used in the dimensioning of cockpit controllers. Figures 1.5, 1.6, and 1.7 provide geometric data on the standard cockpit controllers. Comparison with Figure 1.4 and Table 1.3 shows that several small differences exist.

Reference 1 also contained data on travels for wheel (yoke) and stick controllers (pages 45 and 52), and comparison with the data included here shows again small differences.

This military standard is approved by the Department of Defense and is mandatory for use by all Departments & Agencies of the Department of Defense. Selection for all new engineering and design applications and for repetitive use shall be made from this document.

"Review/user information is current as of the date of this document. For future coordination of changes to this document, draft circulation should be based on the information in the current DODISS."

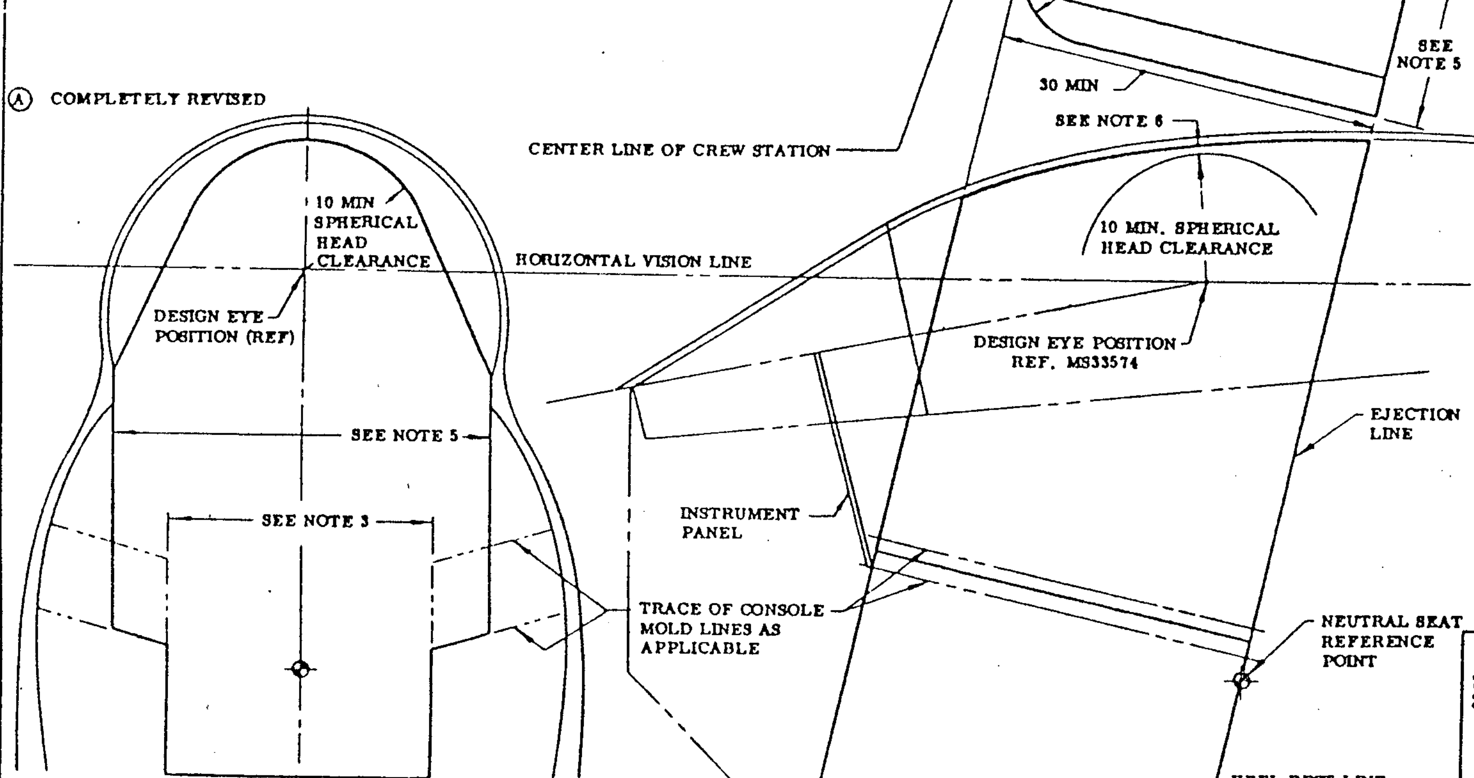
REVIEWER SYMBOLS: USER SYMBOLS:

P.A.	NAVY - AS	TITLE	DIMENSIONS, CLEARANCE, COCKPIT FIXED WING AIRCRAFT	MILITARY STANDARD
Other Cust	ARMY - AV (AMSAV - MN) AF-RTD/SEG/CODE 11			MS33573
PROCUREMENT SPECIFICATION		SUPERSEDES		SHEET 1 OF 1

1. THE 30 INCH EJECTION CLEARANCE LINE SHALL BE MEASURED PERPENDICULAR FROM THE EJECTION LINE OF THE SEAT REFERENCE POINT.
2. ALL MEASUREMENTS ARE BASED UPON THE SEAT REFERENCE POINT AT THE CENTERLINE OF THE SEAT IN THE NEUTRAL POSITION.
3. THERE SHALL BE NO PROJECTIONS, SUCH AS THROTTLES, LANDING GEAR CONTROL, INSTRUMENT PANEL, ETC. INTO THE ESCAPE OPENING THAT WOULD INTERFERE WITH EJECTION.
4. CANOPIES SHALL BE SO ARRANGED THAT WHEN THE PILOT'S HEAD IS IN THE NORMAL POSITION, NORMAL OR EMERGENCY OPERATION OF THE CANOPY SHALL BE SUCH THAT NO PART OF THE CANOPY CAN STRIKE THE PILOT'S HEADGEAR.
5. THIS DIMENSION SHALL BE 26 INCHES FOR AIRCRAFT IN WHICH PRESSURE SUITS ARE NOT EMPLOYED, AND 30 INCHES FOR AIRCRAFT IN WHICH PRESSURE SUITS ARE EMPLOYED.
6. ADDITIONAL CLEARANCE SHALL BE AS SPECIFIED BY THE PROCURING ACTIVITY. eg THERMAL CLOSURE, FACE CURTAIN CONTROL, ETC.
7. DIMENSIONS IN INCHES.

THIS IS A DESIGN STANDARD. NOT USED AS A PART NUMBER.

(A) COMPLETELY REVISED



APPROVED 25 SEP 56 REVISED (A) 5 JUNE 1967

FED. SUP CLASS 1510

DD FORM 672-1 (Coordinated)

*U.S. GOVERNMENT PRINTING OFFICE: 1967-301-511 1234

Figure 1.5 Dimensions and Clearances for Cockpits of Fixed Wing Aircraft

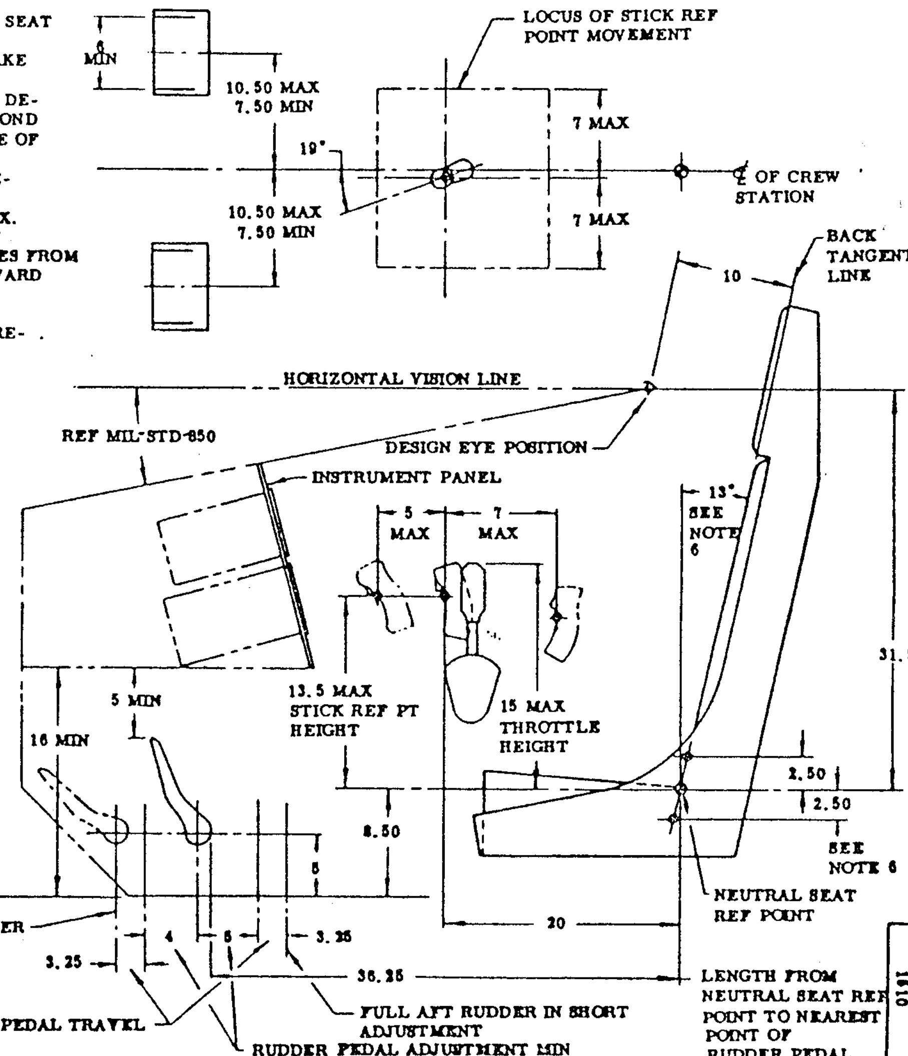
This military standard is approved by the Department of Defense and is mandatory for use by all Departments & Agencies of the Department of Defense. Selection for all new engineering and design applications and for repetitive use shall be made from this document.

"Review/user information is current as of the date of this document. For future coordination of changes to this document, draft circulation should be based on the information in the current DODISS."

REVIEWER SYMBOLS: USER SYMBOLS:

1. ALL MEASUREMENTS ARE BASED UPON THE SEAT REFERENCE POINT AT THE CENTERLINE OF THE SEAT IN THE NEUTRAL POSITION.
2. REFERENCE SPECIFICATION MIL-B-8584 FOR BRAKE PEDAL ANGLES AND DIMENSIONS.
3. THE STICK AND THROTTLE REFERENCE POINT IS DEFINED AS THE POINT AT WHICH THE PILOT'S SECOND FINGER IS IN CONTACT WITH THE FORWARD FACE OF THE CONTROL.
4. RUDDER PEDAL ADJUSTMENT SHALL BE IN INCREMENTS OF 1 INCH OR LESS.
5. BECAUSE OF CATAPULT GRIP REQUIREMENT, MAX. FORWARD THROTTLE MOVEMENT FOR AIRCRAFT EQUIPPED FOR CATAPULTING SHALL BE 20 INCHES FROM NEUTRAL SEAT REFERENCE POINT. MAX. FORWARD THROTTLE MOVEMENT FOR NONCATAPULT AIRCRAFT SHALL CORRESPOND TO THAT OF STICK.
6. FOR SEAT BACK ANGLE AND SEAT ADJUSTMENT REQUIREMENTS FOR EJECTION SEATS IN U.S. NAVY AIRCRAFT. MIL-S-18471 (WEP) AND DRAWING 65A136H1 APPLY.
7. DIMENSIONS IN INCHES

THIS IS A DESIGN STANDARD, NOT USED AS A PART NUMBER



(A) REVISED AND REDRAWN.

APPROVED 24 JUL 56 REVISED (A) 5 JUNE 1967

FED. SUP CLASS 1610

P.A. NAVY-AS

Other Cust: ARMY-AV (AM SAV-MN) AF-RTD/SEG/CODE 11

TITLE: DIMENSIONS, BASIC, COCKPIT, STICK CONTROLLED FIXED WING AIRCRAFT

MILITARY STANDARD MS33574

PROCUREMENT SPECIFICATION | SUPERSEDES: | SHEET 1 OF 1

DD FORM 672-1 (Coordinated)

U.S. GOVERNMENT PRINTING OFFICE: 1967-301-511/1235

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Figure 1.6 Dimensions and Controller Travels for Stick Controlled Fixed Wing Aircraft

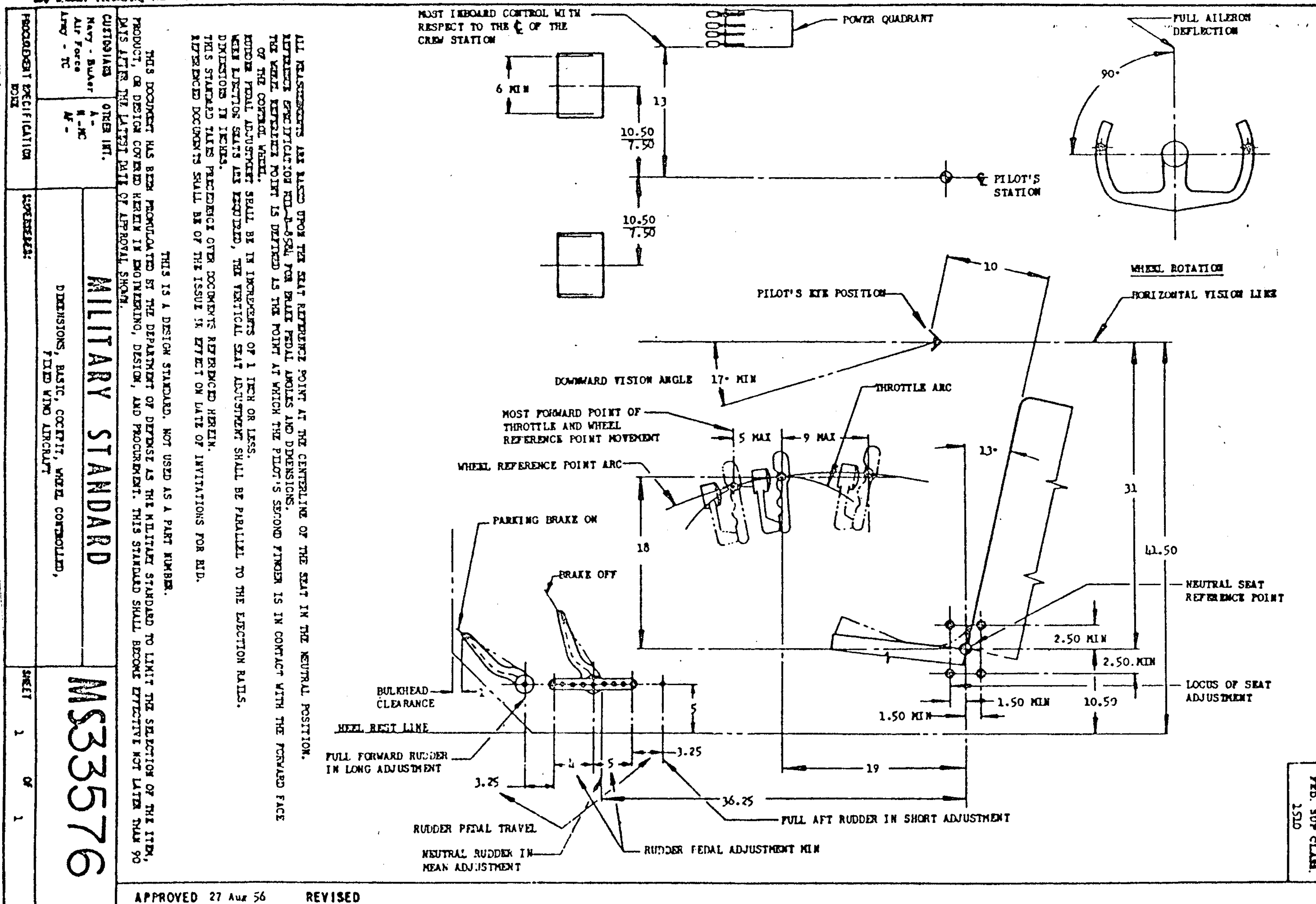

Figure 1.7 Dimensions and Controller Travels for Wheel Controlled Fixed Wing Aircraft

1.3 CONTROL FORCES AND GEARING RATIOS

Control forces required to move the primary flight controls are often calculated from:

$$\underset{(\text{lbs})}{F} = \underset{(\text{ft}^{-1})}{G} \cdot \underset{(\text{ft lbs})}{HM} \qquad (1)$$

The hinge moment HM is in turn calculated from:

$$HM = C_{h_\delta} \, \delta \, \bar{q} \, S_x \bar{c}_x \qquad (2)$$

Reference 2, Chapter 5, contains detailed discussions of how HM is used and calculated in important flight situations. It should be noted that for many airplanes Equations (1) and (2) are not satisfied over the entire range of controller (or control surface) deflections. In many instances the actual relation between F, HM and δ is a non-linear one. An approach to the analysis of control forces in such nonlinear cases is also discussed in Reference 2, Chapter 5.

Table 1.4 presents typical values for G_E, G_A and G_R (as linear approximations) for several airplanes.

Table 1.5 presents typical contoller travels employed in existing single-engine airplanes.

Table 1.6 presents the maximum allowable control forces per FAR 23-143 for single-engine airplanes.

Table 1.4 Example Control Gearing Ratios

Airplane Type	Gearing Ratio		
	Elevator $G_E(ft^{-1})$	Ailerons $G_A(ft^{-1})$	Rudder $G_R(ft^{-1})$
SIAI-Marchetti S211	.696 Stick	.667 Stick	1.419 Pedals
Gates-Learjet M36	.862 Wheel	.392 Wheel	2.290 Pedals
Typical Range for Transport Cockpits (Ref. 3)	.67 to .79 Wheel	—	—
Cessna 303	1.44 Wheel	.50 Wheel	2.30 Pedals

Note: All control forces are defined as:

$$\underset{(lbs)}{F} = \underset{(ft^{-1})}{G} \cdot \underset{(ft\ lbs)}{HM}$$

Table 1.5 Example Controller and Controller Surface Travels

Airplane Type	Travel					
	Elevator		Aileron		Rudder	
	Surface	Wheel	Surface	Wheel	Surface	Pedals
Cessna 172	28° up 23° down	6.6 inch total	20° up 15° down	±90°	±16° relative to waterline	4 inch total
Cessna 210 P	23° up 17° down	7.5 inch total	25° up 15° down	±90°	±24° relative to waterline	2.75 inch total
Cessna 303 (twin)	28° up 19° down	7.2 inch total	25° up 15° down	±80°	±30° perpendicular to hingeline which is 28° swept!	5.3 inch total
Typical Average for Single Engine *	28° up 15° down	±3 inch	20° up 15° down	±85°	±30°	±2 inch

*NOTE: See Also Table 4.1 in Reference 1. There are slight differences!

Table 1.6 Maximum Allowable Control Forces for Conventional Controllers (FAR 23)

Values in pounds of force as applied to the control wheel or rudder pedals	Pitch	Roll	Yaw
(a) For temporary application:			
Stick.	60	30	-
Wheel (applied to rim) . .	75	60	-
Rudder pedal	-	-	150
(b) For prolonged application.	10	5	20

1.4 SIDE-ARM CONTROLLERS

The control force equation (in the linear range) can still be written as Equation (1). Since the control surface size is determined from considerations independent from the type of controller used (see Chapter 2), the hinge moments can be reduced only by "balancing", i.e., reducing of C_{h_δ}.

Because of the very small moment arm associated with side-arm controllers, G in Equation (1) will tend to be larger than for a wheel or stick type controller.

For these reasons it will generally be necessary to employ some form of geared tab arrangement or servo-tab arrangement to provide the pilot with reasonable control forces. There is nothing fundamentally wrong with such control arrangements, and both have been and are being used extensively in larger multi-engine airplanes.

Reference 2, Chapter 5, contains detailed examples of how such geared tab or servo tab controls can be made to work properly.

One minor disadvantage of any tab control arrangement is that the tabs subtract from total control power available. Thus, everything else being equal, the control surfaces in a tab arrangement are going to be larger than those in a non-tab arrangement.

However, in most general aviation single-engine airplanes the lateral controls are oversized for historic reasons so that this argument is probably of no consequence.

In the case of the longitudinal controls, the argument just made would tend to be correct.

No FAR specifications are as yet available for side-arm controllers. Force and travel data on a typical side-arm controller (McFadden) are included in Table 1.7 and Figure 1.8.

Reference 1, Chapter 5.4, contains more controller torque and travel data for side-arm controllers, as measured on 11 pilots.

Table 1.7 Specification for Side-Arm Controller of Figure 1.8

2-Axis Control Force Loading System-Side arm Hand Controller; shall be in accordance with the following specifications:

1.1. System Characteristics

The system shall provide the following range of parameter adjustments with the pitch axis and roll axis forces referenced to the center of the stick grip:

1.1.1. Pitch Axis

A. Maximum Force Output: at least ±50 lbs.

B. Maximum Velocity: at least 25 in/sec.

C. Maximum Damping: at least 0.5 lbs/in/sec.

D. Coulomb Friction: 0 to 5 lbs.

E. Preload (Breakout): 0 to 5 lbs.

F. Deadband (Backlash): 0 to 0.5 in.

G. Maximum Control Travel: ±2 inches (±20°).

H. Maximum Force Gradient: at least 200 lb/in.

I. Position Limits (stops): 10% to 100% of maximum control travel.

1.1.2. Function Generation (stops)

The function generator shall create non-linear force gradients consisting of an initial slope plus four straight line segments either side of zero. Independent adjustment of each breakpoint and slope shall be provided.

1.1.3. Roll Axis

A. Maximum Force Output: at least ±50 lbs.

B. Maximum Velocity: at least 25 in/sec.

C. Maximum Damping: at least 0.5 lb/in/sec.

D. Coulomb Friction: 0 to 50 lbs.

E. Preload (Breakout): 0 to 5 lbs.

F. Deadband (Backlash): 0.5 in.

G. Maximum Control Travel: ±2 inches (±20°).

H. Maximum Force Gradient: at least 200 lbs/in.

I. Position Limits (stops): 10% to 100% of maximum control travel.

J. Function Generation: Same as pitch axis.

1.1.4. Additional Features

A. Trim: Accept pilot pitch and roll, trim switch closures and simulate a trim actuator in each axis such as to null the pitch and roll forces for any control position. The trim rate shall be adjustable over a minimum range of 0.2 to 2 inches/second of control movement. Trim travel limits shall be independently adjustable from 10% to 100% of control travel in each direction.

B. External Inputs: The system, for pitch and roll shall accept ±100 vdc. commands from an external source. Sensitivity of the system to the external inputs shall correspond to the maximum forces specified under paragraph 1.1.1 for ±100 vdc. This provision for external inputs shall function independently, but in conjuction with the other force functions dialed in from the front panels.

C. Outputs: Analog voltage outputs shall be provided which represent the pilot's applied control force, velocity, position, and trim position for use in the computation of the aircraft dynamics within a host computer. Outputs to the host computer shall be ±10 vdc scaling.

1.2. Control Loader Actuators

1.2.1. Response:

The pitch and roll loader actuators shall be capable of at least 50 Hz natural frequency force loop response.

1.2.2. Arrangement:

The acutators shall be arranged such that the outermost axis shall provide the roll motion of the pilot's control stick while the inner axis shall provide the pitch motion of the pilot's control stick.

1.2.3. Loader Characteristics:

A. Control Stick Grip: The control grip shall be Air Force type B8A and shall be rotated 19° counterclockwise from longitudinal axis with capability for 0°, and 19° clockwise adjustments. The grip shall be removable with all switches brought out through a suitable connector.

B. Control Motion: The pitch axis shall provide a minimum travel of ±20 degrees. Center may be readjusted to be located at any position within this range of travel. The roll axis shall provide a minimum of ±20 degrees travel about the center of the control stick.

C. Control Force Transducer: The force transducer for each axis shall have a linearity of better than 1.0 percent full scale.

Table 1.7 Specification for Side-Arm Controller of Figure 1.8 (continued)

D. Control Force Drift: The force drift in each axis shall not exceed 1.0 percent of full torque over an 8-hour period.

E. Control Coulomb Friction: The total friction level of each control loader measured at the control grip shall not exceed 0.10 lb.

F. Control Cross Coupling: There shall be detectable cross coupling between axes in either force or position outputs.

G. Control Stability: The loader system shall not exhibit any detectable instabilities over the total range of parameter adjustments.

H. Loader Mounting: The pitch and roll control loader shall have adequate provisions for mounting in front of or at either side of the pilot in a cockpit simulator.

I. Safety: Provisions to sense excess rate of change of velocity being developed by the loaders and cause a shutdown shall be provided. A relay shall be provided which when closed will illuminate a warning light for remote indication of shutdown.

1.3. Power

Electrical Power: The Government will furnish 115V VAC, 60 Hz, 15A, 208/220 VAC, 3 Ø, 60 Hz, 3HP, and 28 vdc, 2A power at the installation site. The system shall operate from this available power.

1.4. Interconnecting Cables

The Contractor shall furnish all interconnecting cables between the analog computer and loader unit. All interconnecting cable lengths shall be 20 feet in length.

1.5. Documentation

1.5.1. Drawings:

A. A complete mechanical and electrical description of the control loader system shall be delivered within 90 days after the date of contract award to allow the Government to prepare the installation site. The description shall include as a minimum standard dimensional drawings of each unit clearly showing mounting details, hydraulic connections, etc., all input/output signal interfaces, and the electrical and hydraulic interface requirements.

B. Two (2) sets of drawings shall be furnished with the system when delivered. These drawings shall include as a minimum complete wiring diagrams, PC board layouts and shall cross-reference component designators on wiring diagrams to PC board and/or chassis designators. All parts shall be identified as to manufacturer, rating, number, and type.

1.5.2. Operation and Maintenance Manual:

An operation/maintenance manual shall be furnished with the system when delivered which shall contain as a minimum a section on theory of operation, system setup, adjustment and maintenance procedures plus a separate section devoted to explanation of adjustment of all system parameters, system compensation (including feedback circuit diagrams) and servo analysis; recommended spare parts also shall be included.

1.6. Installation, Instructions and Demonstration

Contractor shall install the system in NASA Building 1268A, instruct NASA personnel in system operation and maintenance, and demonstrate that the system meets the performance specifications.

1.7. Final Acceptance

Final acceptance shall depend upon satisfactory performance demonstration required under paragraph 1.6 above.

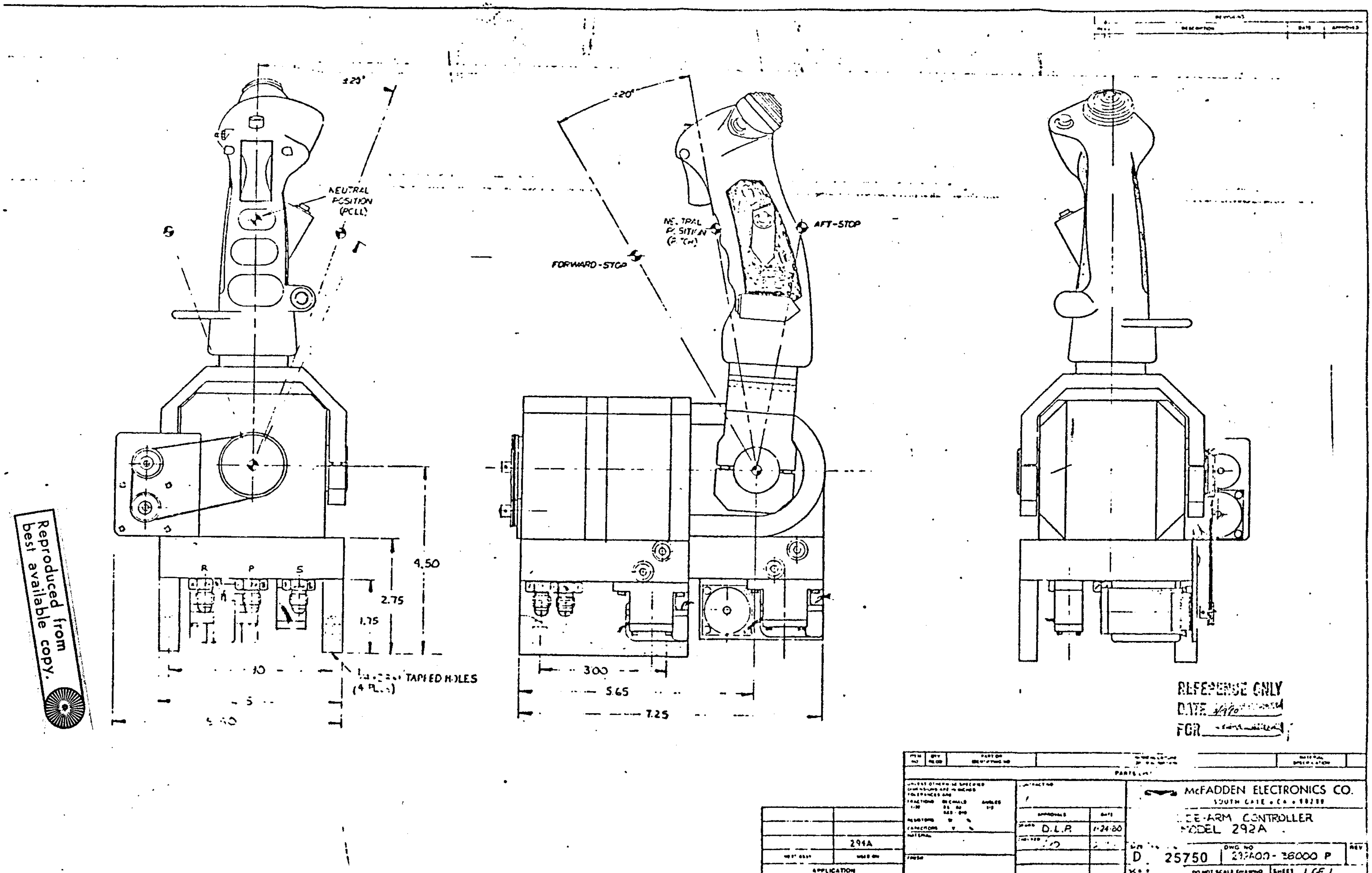

Figure 1.8 Geometry and Travel for Typical Side-Arm Controller

1.5 BROLLEY CONTROLLER

Because of the increased mechanical complexity of the Brolley system plus the fact that four would be required in a typical single-engine application, this is probably not a cost-effective controller solution for light airplanes.

Travels and forces for Brolleys would tend to be somewhat similar to travels and forces for wheel arrangements.

The NASA 737 TCV research cockpit employs a Brolley system.

No data on Brolley's are included in this report.

CHAPTER 2

SIZE AND LOCATION OF CONTROL SURFACES

The size and location of control surfaces in airplanes is essentially independent of the type of cockpit controls considered under 1.

Control surface size and location in typical single-engine airplanes are determined from the following criteria:

2.1 Roll Axis Criteria

2.2 Yaw Axis Criteria

2.3 Pitch Axis Criteria.

2.1 ROLL AXIS CRITERIA

Ailerons and spoilers must be sized so that minimum roll performance criteria are satisfied.

For FAR 23 certified airplanes these criteria are given in FAR 23.157. From these criteria and the roll performance analysis method of Reference 2 (Chapter 6), it is possible to compute for a given airplane configuration the value required of the roll control power derivative, $C_{\ell_{\delta_A}}$, needed to satisfy the roll performance criteria.

Knowing the required magnitude of $C_{\ell_{\delta_A}}$, it is then possible with methods such as Reference 4 (Chapter 11) and Reference 5 (Section 6) to size and locate the ailerons or the spoilers.

In so doing, a larger number of practical constraints need to be considered. Typical of such constraints are:

1) Location of rear span

2) Extent of flaps needed

3) Type of airfoil used

4) Hinge moment/Lateral control force trades

5) Mass balancing.

Constraint number 1) usually means that the maximum aileron chord (or the spoiler hinge line) is determined by the location of the rear span. The latter is normally driven by structural considerations.

Constraint number 2) usually means that the allowable span of the aileron is dictated by the required span of any trailing edge high lift devices. If full span high lift devices are required, then spoilers may have to be used for roll control. An alternative which can sometimes be accepted is a combination of flaps and ailerons (flaperons). The aileron movement of the flaperon in that case is arranged mechanically just like a conventional aileron.

Constraint number 3) has significant consequences for the hinge moments.

Constraint number 4) usually ends up designing the aileron nose shape, hinge-line location and tabs needed to decrease (or, as the case may be, to increase aileron hinge moment.

Hinge moment tailoring and the associated detailed mechanical design of the control system for spoilers is still more or less a "black art"! Little or no systematic design information is available on this subject.

Constraint number 5) [frequently together with constraint number 4)!] usually results in the need for a horn (to minimize control surface weight), which in turn affects lateral control power and lateral control hinge moment.

2.2 YAW AXIS CRITERIA

Rudders in single-engine airplanes must be sized so that the airplane can be slipped and controlled on the ground. The criteria of FAR 23.177 and FAR 23.233 apply. In addition, rudders may have to be sized for spin recovery.

For spin sizing, the guidelines of Reference 6 (pages 616 and 617) are still used even though they are probably not correct.

For sideslip sizing of the rudder, the methods of Reference 3 (Part B) may be used.

For cross-wind control in the air, the previous reference can also be used. For cross-wind control on the runway, no reference was found; however, a mathematical approach similar to that used in the take-off rotation problem of Reference 2, Chapter 5, can be employed.

From the calculations needed to show compliance with the FAR's, the value of the rudder control power derivative, $C_{n_{\delta_R}}$, can be computed. Knowing the required magnitude of $C_{n_{\delta_R}}$, it is possible to determine the required rudder size from Reference 4 (Chapter 12) or Reference 5 (Section 6).

In so doing, a number of practical constraints need to be considered. Typical of such constraints are:

1) Location of rear span
2) Hinge moments and their effect on rudder pedal forces
3) Mass balancing.

Constraint number 1) usually implies a trade-off between vertical tail size, location and shape as required by directional stability considerations and vertical tail strength under sudden rudder applications at high speed.

Constraint numbers 2) and 3) involve trade-offs between requirements for low rudder weight, hinge moment tailoring and rudder pedal control force requirements.

2.3 PITCH AXIS CRITERIA

Longitudinal controls need to be sized so that the airplane satisfies FAR 23.145, FAR 23.155 and FAR 23.161. In addition the longitudinal controls must be sized to provide rotation to lift-off attitude at or below the lift-off speed.

Methods for computing longitudinal control power, $C_{m_{\delta_E}}$, (elevator is used here, but this could be a stabilator or a canardvator) are discussed in detail in Reference 2, Chapter 5. Knowing $C_{m_{\delta_E}}$ required, it is possible to size the control surface with the methods of Reference 4 (Chapter 10) or Reference 5 (Section 6).

In so doing, a number of practical constraints need to be considered. Typical of such constraints are:

1) Rear spar location of horizontal tail
2) Mass balancing
3) Hinge moments and their effect on control forces.

Constraint number 1) is closely tied with the following sizing requirements for the horizontal tail:

a) trim requirement at forward c.g.
b) nosewheel lift-off at lift-off speed
c) static stability
d) maneuvering requirement.

Constraint number 2) is a critical one in terms of weight and often results in the need for a "horn-balance." This horn-balance in turn ties in with constraint 3).

Achieving harmonious control forces in all three axes is a difficult task in conventional (reversible) control systems. It is normally achieved after a considerable amount of hinge moment and balance tailoring in flight test.

2.4 EXAMPLE CONTROL SURFACE DATA

Tables 2.1 and 2.2 provide tabulated data on typical aileron, elevator, rudder and flap sizes used in single-engine and in twin-engine general aviation airplanes.

All of these airplanes employ conventional stick-pedal or wheel-pedal controllers.

To a first approximation these control surface sizes and locations would also apply to other types of cockpit controllers. If, as a result of using a controller which has a high gearing ratio (such as a side-arm controller), either large geared tabs or large servo tabs need to be employed, then the control surface area may have to be increased. (See also Section 1.4.)

The amount by which the surfaces would have to be increased depends to a first order of approximation on the tab-to-surface-chord ratio (for full span tabs) or on the tab-area-moment-to-surface-area ratio (for partial span tabs).

Roughly speaking, a 10% chord full span tab would require a 10% larger surface chord. Obviously the practical constraints mentioned in Sections 2.1, 2.2 and 2.3 will alter this to a significant degree and probably also cause changes in control surface spans.

In each case a detailed design trade study will have to be made before a decision can be reached.

Table 2.1 Volume Coefficient, Geometric and Control Surface Data for Single Engined General Aviation Aircraft

Type	W kg	b_w m	S_w m^2	$\bar{c}_m$ m	A	Λ deg	λ	Γ deg	S_v m^2	S_h m^2	ℓ_v m	ℓ_h m
1. Fairey "Tipsy Nipper"	300	6.00	7.50	1.22	4.80	0	0.825	+8.5	0.585	1.33	2.58	2.34
2. Gardan G. Y. -80	1,000	9.70	12.50	1.33	7.50	0	0.590	+7	1.58	2.48	3.58	3.84
3. Mooney M.20-MK 20	1,112	10.67	15.50	1.57	7.35	0	0.500	+4	1.19	3.50	3.91	3.91
4. Wassmer WA-40 "Super IV"	1,200	10.00	16.00	1.60	6.20	0	1.00	+6	1.16	2.97	4.67	4.71
5. Cessna 172	1,000	10.97	16.26	1.49	7.46	0	0.68	+2	1.71	3.27	4.39	4.32
6. Pilatus P.3 "Trainer"	1,500	10.40	16.30	1.63	6.62	0	0.588	+3	1.47	3.26	4.36	4.86
7. Beechcraft H.35 "Bonanza"	1,315	10.00	16.49	1.70	6.05	0	0.550	+6	1.18*	2.78*	4.51	4.51
8. Beechcraft 33 "Debonair"	1,315	10.00	16.50	1.75	6.05	0	0.500	+5.5	1.30	3.47	4.64	4.72
9. Piper PA-24-180 "Comanche"	1,156	10.96	16.53	1.35	7.20	0	0.445	+5	1.24	3.00	3.92	4.36
10. Maurane Sauinier MS 760 "Paris"	3,470	10.15	17.30	1.86	5.95	0	0.746	+8	1.57	2.76	4.52	5.05
11. Fouga CM.170 "Magister"	3,200	11.30	17.30	1.66	7.40	10	0.400	0	2.60*	3.75*	4.00	4.00
12. Lockheed-Azcarate LA-60	1,685	12.00	19.51	1.66	7.20	0	0.740	+1	2.17	4.75	4.77	4.93
13. Helio H 391-B "Courier"	1,362	11.89	21.46	1.83	6.58	0	1.00	+1	2.40	3.48	5.65	5.42
14. De Haviland DHC-2 "Beaver"	2,315	14.64	23.20	1.59	9.20	0	1.00	+2	3.72	4.50	5.88	6.28
15. Auster B.8 "Agricola"	1,790	12.80	23.68	2.12	6.92	0	0.646	+7	2.17	4.42	4.91	4.75
16. Pilatus P.C.-6 "Porter"	1,800	15.20	28.50	1.86	8.10	0	1.00	+3	2.36	5.92	5.58	6.17
17. Scottish Aviation "Prestwick Pioneer"	2,450	16.08	38.40	2.41	6.67	0	1.00	+1	2.18	8.56	5.23	6.23
18. De Haviland DHC 3 "Otter"	3,630	17.69	39.00	2.45	8.97	0	1.00	+2	5.60	7.80	7.32	7.70

*V-Tail Areas given are the projected vertical and horizontal areas.

NOTE: Data in Table 2.1 are taken from Aircraft Design, Volumes I, II, and III, by the staff of Prof. H. Wittenberg, Technological University of Delft, Holland.

Table 2.1 Volume Coefficient, Geometric and Control Surface Data for Single Engined General Aviation Aircraft (continued)

Type	$\frac{S_v}{S_w}$	$\frac{S_v \ell_v}{S_w b_w}$	$\frac{S_h}{S_w}$	$\frac{S_h \ell_h}{S_w \bar{c}_w}$	S_a m^2	S_e m^2	S_r m^2	S_f m^2	$\frac{S_a}{S_w}$	$\frac{S_e}{S_h}$	$\frac{S_r}{S_v}$	$\frac{S_f}{S_w}$
1. Fairey "Tipsy Nipper"	0.078	0.033	0.175	0.336	0.90	0.86	0.49	-	0.120	0.646	0.836	-
2. Gardan G. Y. -80	0.126	0.046	0.198	0.570	0.68	-	0.38	1.30	0.055	-	0.24	0.104
3. Mooney M.20-MK 20	0.077	0.028	0.226	0.563	1.03	1.11	0.45	1.60	0.066	0.317	0.368	0.103
4. Wassmer WA-40 "Super IV"	0.072	0.034	0.185	0.546	1.275	-	0.554	1.105	0.080	-	0.477	0.069
5. Cessna 172	0.105	0.042	0.201	0.561	1.70	1.84	0.870	1.97	0.105	0.563	0.508	0.121
6. Pilatus P.3 "Trainer"	0.091	0.038	0.200	0.596	1.32	1.40	0.80	1.80	0.081	0.430	0.542	0.110
7. Beechcraft H.35 "Bonanza"	0.107	0.048	0.167	0.460	1.07	0.934*	0.60*	2.16	0.064	0.336	0.336	0.137
8. Beechcraft 33 "Debonair"	0.079	0.037	0.210	0.570	1.12	1.60	0.49	1.25	0.065	0.461	0.377	0.076
9. Piper PA-24-180 "Comanche"	0.075	0.027	0.181	0.585	1.30	-	0.403	1.86	0.079	-	0.515	0.113
10. Maurane Saulnier MS 760 "Paris"	0.091	0.041	0.160	0.430	1.62	0.960	0.506	1.44	0.94	0.348	0.322	0.083
11. Fouga CM.170 "Magister"	0.150	0.053	0.253	0.610	1.07	1.28*	0.905*	1.18	0.062	0.341	0.341	0.068
12. Lockheed-Azcarate LA-60	0.111	0.062	0.243	0.725	2.26	1.65	0.606	4.17	0.116	0.348	0.280	0.214
13. Helio H 391-B "Courier"	0.112	0.053	0.162	0.481	1.92	-	0.99	3.54	0.089	-	0.412	0.165
14. De Haviland DHC-2 "Beaver"	0.160	0.064	0.194	0.770	2.28	2.02	0.809	1.86	0.098	0.448	0.217	0.080
15. Auster B.8 "Agricola"	0.092	0.035	0.187	0.420	2.88	1.58	1.29	1.03	0.122	0.377	0.595	0.043
16. Pilatus P.C.-6 "Porter"	0.083	0.030	0.208	0.690	2.80	2.44	0.96	2.80	0.098	0.411	0.406	0.098
17. Scottish Aviation "Prestwick Pioneer"	0.057	0.019	0.223	0.580	4.00	4.43	1.21	6.25	0.104	0.517	0.555	0.163
18. De Haviland DHC 3 "Otter"	0.140	0.060	0.200	0.630	2.44	3.94	2.10	9.10	0.062	0.505	0.375	0.233

*V-Tail Areas given are the projected vertical and horizontal areas.

NOTE: Data in Table 2.1 are taken from Aircraft Design, Volumes I, II, and III, by the staff of Prof. H. Wittenberg, Technological University of Delft, Holland.

Table 2.2 Volume Coefficient, Geometric and Control Surface Data for Twin Engined Business Aircraft and Airliners

	Type	W kg	b_w m	S_w m^2	$\bar{c}_w$ m	A	Λ deg	λ	Γ deg	S_v m^2	S_h m^2	ℓ_v m	ℓ_h m
1.	Simmering-Graz-Pauker M222 "Flamingo"	1,450	11.00	17.10	1.65	7.1	0	0.515	+3.5	1.54	2.74	4.39	4.79
2.	Beechcraft M.50 "Twin Bonanza"	3,175	13.81	25.83	1.99	7.51	0	0.430	+7	2.68	6.58	5.43	5.34
3.	Dornier Do.28	2,330	14.15	24.20	1.66	8.2	0	1.00	+1.5	2.20	3.96	5.50	5.33
4.	Grumman YAO-1 "Mohawk"	4,580	12.80	30.60	2.46	5.35	0	0.515	+8	8.71	8.30	6.50	6.50
5.	De Haviland "Dove"	3,992	17.40	31.12	2.03	9.7	0	0.306	+4	2.60	5.80	6.12	6.65
6.	Max Holste M.H. 260 "Super Broussard"	9,600	21.85	54.50	2.60	8.8	0	0.580	+3	6.91*	14.35	8.95	8.48
7.	Grumman G-159 "Gulfstream"	14,074	23.93	60.60	2.55	9.45	0	0.420	+9.5	9.48	13.42	8.75	9.30
8.	Scottish Aviation "Twin Pioneer"	6,350	23.33	62.24	2.59	8.73	0	0.714	+2/+3	15.54	15.53	7.51	7.56
9.	Fokker F27 "Friendship"	17,000	29.00	70.00	2.575	12.0	0	0.40	+2.5	14.20*	16.00	10.50	10.50
10.	Avro 748 "Feeder Liner"	14,970	29.00	74.0	2.77	12.4	0	0.42	+6.5	10.50	22.10	9.20	9.56
11.	Avro 771	33,600	23.60	74.4	3.46	7.5	30	0.286	+3	14.50	13.72	7.98	11.20
12.	British Aircraft Corp. BAC.107	22,000	24.90	76.5	3.33	8.2	20	0.345	+2.5	10.70	19.90	8.75	11.30
13.	Handley Page "Dart Herald"	17,690	28.89	82.4	3.14	10.0	0	0.522	+4	16.80*	23.41	10.70	11.00
14.	De Haviland DHC.4 "Caribou"	11,793	29.30	84.72	3.04	9.9	0	0.435	+4.5	18.22	21.36	12.45	12.45
15.	15 NAMC YS 11 (Nippon YS11)	22,800	32.0	94.8	3.25	10.8	0	0.348	+4.3	14.50	21.30	11.82	13.10
16.	Hurel Dubois H.D. 321	18,700	45.30	100.00	2.14	20.2	0	0.620	+4.5	19.98*	24.50	12.15	11.90
17.	Hurel Dubois H.D. 37	23,200	46.36	102.00	2.25	21.0	0	0.645	+4.5	14.95*	26.50	12.90	12.75
18.	Sud Aviation SE 210 "Caravelle"	47,000	34.40	146.7	4.85	8.02	0	0.352	+3	15.50	21.55	11.80	13.15
19.	Tupolev Tu 104	70,000	35.00	188.0	5.84	6.5	40.5/ 37.5	0.333	-	19.75	38.60	17.30	17.90

NOTE: Data in Table 2.2 are taken from Aircraft Design, Volumes I, II, and III, by the Staff of Prof. H. Wittenberg, Technological University of Delft, Holland.

*Dorsal Fin NOT Accounted for in S_v

Table 2.2 Volume Coefficient, Geometric and Control Surface Data for Twin Engined Business Aircraft and Airliners (continued)

	Type	$\frac{S_v}{S_w}$	$\frac{S_v \ell_v}{S_w b_w}$	$\frac{S_h}{S_w}$	$\frac{S_h \ell_h}{S_w \bar{c}_w}$	S_a m^2	S_e m^2	S_r m^2	S_f m^2	$\frac{S_a}{S_w}$	$\frac{S_e}{S_h}$	$\frac{S_r}{S_v}$	$\frac{S_f}{S_w}$
1.	Simmering-Graz-Pauker M222 "Flamingo"	0.090	0.036	0.160	0.460	1.21	0.731	0.520	1.73	0.071	0.267	0.338	0.101
2.	Beechcraft M.50 "Twin Bonanza"	0.104	0.041	0.254	0.683	1.29	1.62	1.18	3.51	0.050	0.270	0.470	0.135
3.	Dornier Do.28	0.090	0.035	0.163	0.520	1.38	1.56	0.85	1.75	0.057	0.394	0.386	0.072
4.	Grumman YAO-1 "Mohawk"	0.285	0.145	0.270	0.710	3.56	1.82	2.05	3.34	0.120	0.219	0.235	0.112
5.	De Haviland "Dove"	0.084	0.029	0.187	0.610	2.00	2.27	1.27	2.68	0.064	0.392	0.488	0.086
6.	Max Holste M.H. 260 "Super Broussard"	0.125	0.052	0.270	0.880	3.82	5.16	3.15	9.90	0.070	0.360	0.455	0.182
7.	Grumman G-159 "Gulfstream"	0.156	0.057	0.222	0.80	4.05	4.24	3.83	9.52	0.067	0.315	0.405	0.157
8.	Scottish Aviation "Twin Pioneer"	0.250	0.080	0.250	0.75	4.42	4.82	5.64	9.70	0.071	0.310	0.362	0.156
9.	Fokker F27 "Friendship"	0.203	0.073	0.228	0.93	3.50	3.17	3.06	6.90	0.050	0.198	0.216	0.099
10.	Avro 748 "Feeder Liner"	0.142	0.045	0.299	1.04	5.13	7.43	4.85	9.57	0.069	0.340	0.460	0.129
11.	Avro 771	0.195	0.066	0.185	0.60	2.58	4.04	4.00	12.90	0.035	0.294	0.276	0.174
12.	British Aircraft Corp. BAC.107	0.140	0.049	0.260	0.88	4.90	8.87	3.60	6.75	0.064	0.445	0.337	0.088
13.	Handley Page "Dart Herald"	0.204	0.076	0.284	1.00	5.53	6.61	4.15	15.06	0.067	0.282	0.247	0.183
14.	De Haviland DHC.4 "Caribou"	0.215	0.091	0.252	1.03	2.25	7.99	7.80	8.60	0.027	0.374	0.428	0.102
15.	15 NAMC YS 11 (Nippon YS11)	0.153	0.057	0.225	0.90	4.78	5.42	4.75	19.62	0.050	0.254	0.330	0.207
16.	Hurel Dubois H.D. 321	0.200	0.053	0.245	1.36	7.00	7.45	6.21	15.80	0.070	0.304	0.310	0.158
17.	Hurel Dubois H.D. 37	0.145	0.041	0.260	1.47	5.66	9.00	6.12	7.38	0.055	0.340	0.410	0.072
18.	Sud Aviation SE 210 "Caravelle"	0.106	0.036	0.147	0.40	7.84	6.45	5.50	24.70	0.053	0.300	0.365	0.168
19.	Tupolev Tu 104	0.106	0.052	0.235	0.722	8.40	10.65	5.75	16.15	0.045	0.273	0.291	0.086

NOTE: Data in Table 2.2 are taken from Aircraft Design, Volumes I, II, and III, by the Staff of Prof. H. Wittenberg, Technological University of Delft, Holland.

CHAPTER 3

INTERFACING OF CONTROLLERS WITH CONTROL SURFACES

3.1 GENERAL

Table 3.1 depicts existing and most probable interfaces between control surfaces and controllers. By direct link, either a cable or a push-pull system is meant. By tab, either a geared tab or a servo- (perhaps spring-) tab is meant.

Table 3.1 Interfacing of Controllers with Control Surfaces

	Aileron	Spoiler	Elevator	Stabilator	Rudder
Wheel	Direct Link or Tab	Direct Link	Direct Link or Tab	Tab	
Stick	Direct Link or Tab	Direct Link	Direct Link or Tab	Tab	
Pedal					Direct Link or Tab
Side-Arm	Probably Tab	Probably Direct Link but needs research	Probably Tab	Tab	
Pulley	Direct Link or Tab	Direct Link	Direct Link or Tab	Direct Link or Tab	

3.2 SPOILERS

Spoilers have been used on airplanes equipped with hydraulic (non-reversible) flight controls. In such a case the type of cockpit controller which interfaces with a spoiler is not important: feedback of hinge moments to the cockpit controller does not occur.

Spoilers have been used on airplanes equipped with cable or push-pull driven flight control systems in only a few cases. Examples are:

a) Many Robertson STOL Conversions

b) Mitsubishi Solitaire & Musquetaire

c) KU/NASA Redhawk and ATLIT

Since approximately linear "pilot-feel" is a requirement for good roll control in any airplane and since spoiler hinge moments tend to be highly nonlinear, a design problem does exist. However, spoilers have been nicely matched to wheel-type control systems by carefully tailoring spoiler hinge moments in such systems.

There is no reason why similar tailoring could not be done in the case of stick-controls, side-arm controls or Brolley controls.

However, in the case of side-arm controls, the problem is not so easy and probably needs a significant amount of flight testing to be resolved satisfactorily. The KU/NASA Redhawk is equipped with a spoiler system (tied to left wheel) <u>and</u> an aileron system (tied to right wheel) and could be used in a flight test program aimed at solving this problem.

3.3 AERODYNAMIC CONTROLS

With this type of controls a set of valves is usually manipulated by the pilot. Apart from friction in the valves, linearity (or good "pilot-feel") can be assured with a conventional spring.

This type of control is workable in combination with any type of cockpit controller, and no significant hinge moment problems are expected.

No production versions of this type of system have been built as yet. NASA LaRC is conducting experiments with this system on a single engine light airplane.

3.4 TAB CONTROLS

Tab controls have been used primarily on airplanes where the size of the control surfaces is so large (or the dynamic pressure is so high) that pilots can no longer overcome the hinge moments without assistance. Figures 3.12 through 3.15 of Reference 1 illustrate such systems.

Several light airplanes also employ tab control systems. Examples are the Cessna Cardinal and the Piper Warrior.

Since tab hinge moments are very small, gearing tabs to any type of cockpit controller (including side-arm controllers) should not present any major problems.

REFERENCES

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